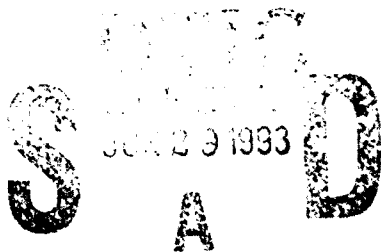# AD-A266 192

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Spatial and Frequency Diversity in Lidar Systems

Introduction

The research is concerned with the signal to noise ratio of LIDAR signals. LIDAR is a remote sensing technique using light to gather information on molecular concentrations. wind velocities, and temperatures in the atmosphere on a temporally and spatially resolved basis. Our interest is in the statistical optics of the detection process rather than the data that might be collected in the ambient atmosphere and our experiments, therefore, are carried out in the laboratory.

The laboratory experiments are concerned with fluctuations in LIDAR measurements. LIDAR signals typically arise from the backscatter of laser radiation from aerosols, and the return signal at the detector plane is spatially distributed in a speckle pattern. The contrast ratio in the pattern is unity so that an estimate of the average intensity from the intensity measured over a single speckle-area yields a signal-to-noise ratio of unity. This assumes that additive noise such as shot noise is negligible. Signal/noise cannot be improved by increasing the signal since the speckle noise is multiplicative. Averaging over N **uncorrelated** speckles can be used to improve signal/noise by a factor $N^{1/2}$.

There are three ways in which fluctuations can be reduced: time averaging. spatial diversity, and frequency diversity [Schotland et al, 1988; Wallace, 1953]. Time averaging is straightforward. An average is taken over N laser pulses separated by no less than the speckle coherence time of typically 1 msec. The penalty of time resolution coarsened to N msec is often unacceptable. Spatial diversity uses the signal from N spatially distinct speckles. This becomes complicated if heterodyne detection is used to accommodate weak backscatter or to allow the measurement of Doppler shifts and hence wind velocities. Since the variation of phase over the
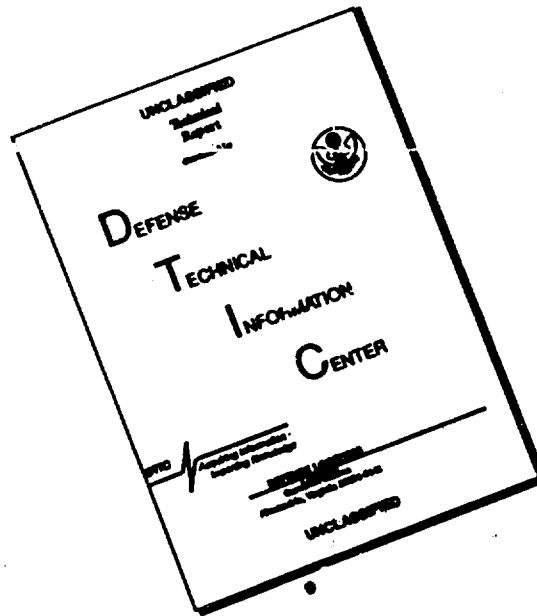
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speckle pattern is as severe as but uncorrelated with the intensity variation, and since heterodyne detection is a phase sensitive process, it turns out that one must use an array of N speckle-sized detectors rather than one large detector. Frequency diversity refers to the use of a transmitted laser beam containing N components sufficiently separated in frequency for their speckle patterns at the detector to be mutually uncorrelated. Frequency diversity has not previously been used in LIDAR. The objective of our laboratory studies is to demonstrate and understand the effects of spatial and frequency diversity on backscattered radiation.

Experimental arrangement

Output from a 4-mw cw neodymium yag laser is phase modulated at 560 MHz; the carrier and one sideband constitute the two frequencies studied. The laser beam containing these two frequencies is brought to a loose focus (confocal parameter 0.25 m) in the scattering region. Backscattered light is heterodyne detected using a second neodymium yag laser as local oscillator detuned about 400 MHz from the carrier, and is digitized and recorded by a Tektronix SCD1000 Transient Digitizer. Recorded signals are Fourier analyzed to yield the scattered intensity for each of the two frequency components so that the correlation between the two components can be studied as a function of the scattering center distribution.

Various spatial distributions of scatterers were of interest. A chalk surface served well as a single scattering plane, but a useful approximation to a continuous scattering distribution required something with large backscatter and low absorption in order to get acceptably large scattered signals. The solution was to use many (six) microscope slides dusted with 20 μm aluminum powder and placed in the beam at Brewsters angle. Experiments with the number of scattering planes reduced to two were also informative.

Results

The signal to noise ratio arising from additive noise (shot and thermal noise) is better than three to one and we ignore these noise sources here for simplicity. Under this assumption it can be shown that, for two scattering planes (n = 2) separated by distance d, the correlation coefficient between two scattered frequencies separated by f is given by:

$$\rho_2 = \cos^2\left(2\pi \, \frac{fd}{c}\right)$$

This is, essentially, a Fourier transform of the scatterer distribution. Figure 1 shows experimental data consistent with this expectation, with some additional decorrelation arising from additive noise. It should be emphasized that there are no free parameters in this comparison. In general, for n scattering planes, equally separated within a total distance d, the correlation coefficient is given by:

$$\rho_n = \frac{1}{n^2} \frac{\sin^2\left(2\pi \cdot \frac{n}{n-1} \cdot \frac{fd}{c}\right)}{\sin^2\left(2\pi \cdot \frac{1}{n-1} \cdot \frac{fd}{c}\right)}$$

Figure 2 shows ρ_2, ρ_6, and ρ_∞ plotted as a function of the modified length d', where d' = n / (n - 1) d. It can be seen from Figure 2 that, in terms of this modified length, six scattering planes does provide a good approximation to a continuous distribution of scatterers. Figure 3 shows a comparison between experimental results for 6 scattering planes and ρ_6. Here again, with no adjustable parameters, and allowing for the decorrelating effect of additive noise, the agreement is good.

Conclusion

We have demonstrated how the decorrelation between two signals backscattered from a continuous scatterer distribution of length d. and differing in frequency by f. depends on the relation between f and d. This is relevant to range gated LIDAR with range resolution d. where the use of two (N) uncorrelated signals (frequency diversity) allows the signal to noise ratio arising from speckle to be reduced by a factor $\sqrt{2}$ ($\sqrt{N}$).

References

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P.R. Wallace. Can. J. Phys., **31**, 995(1953).
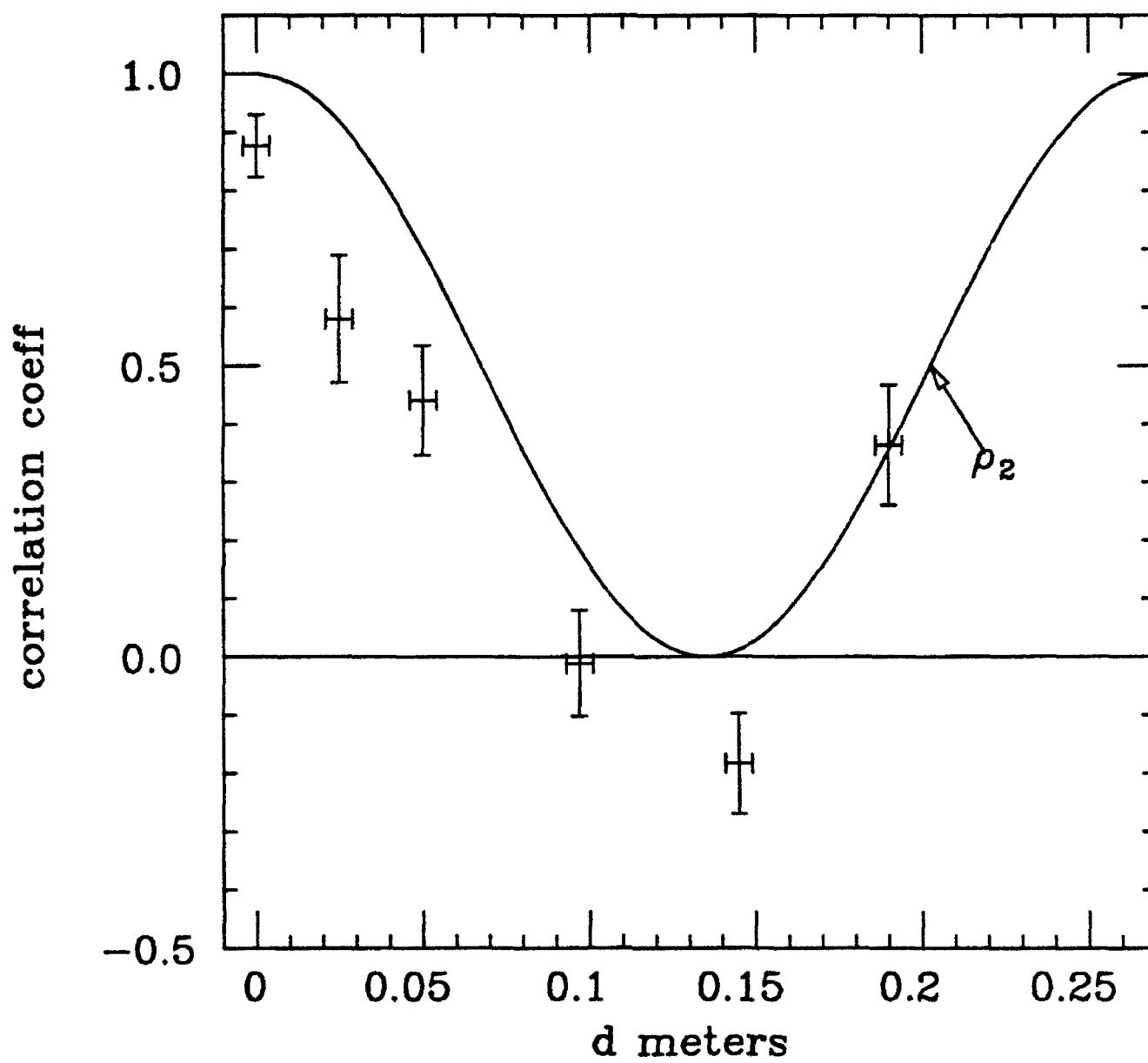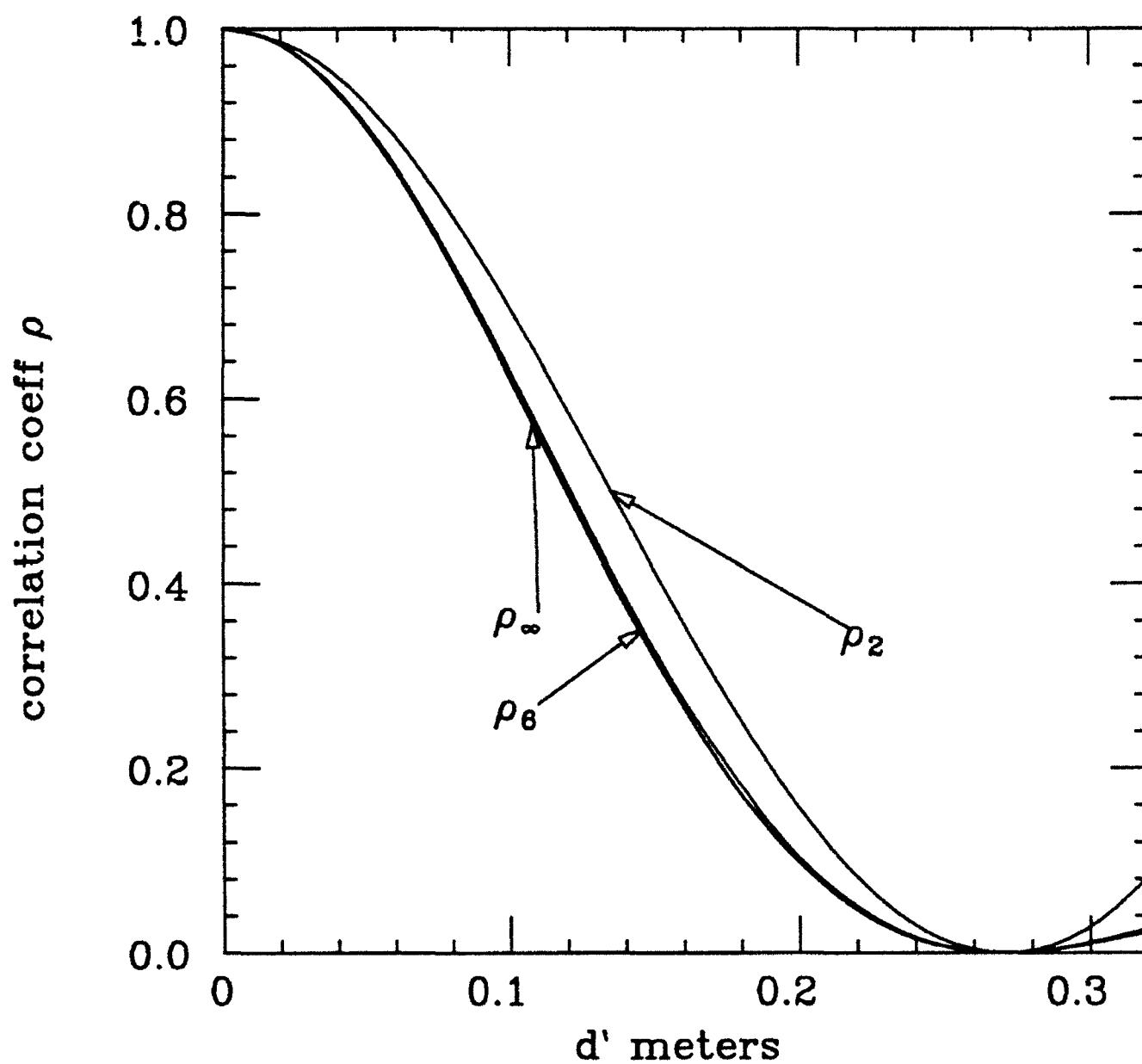
n=2; 2 scattering planes

Fig. 1

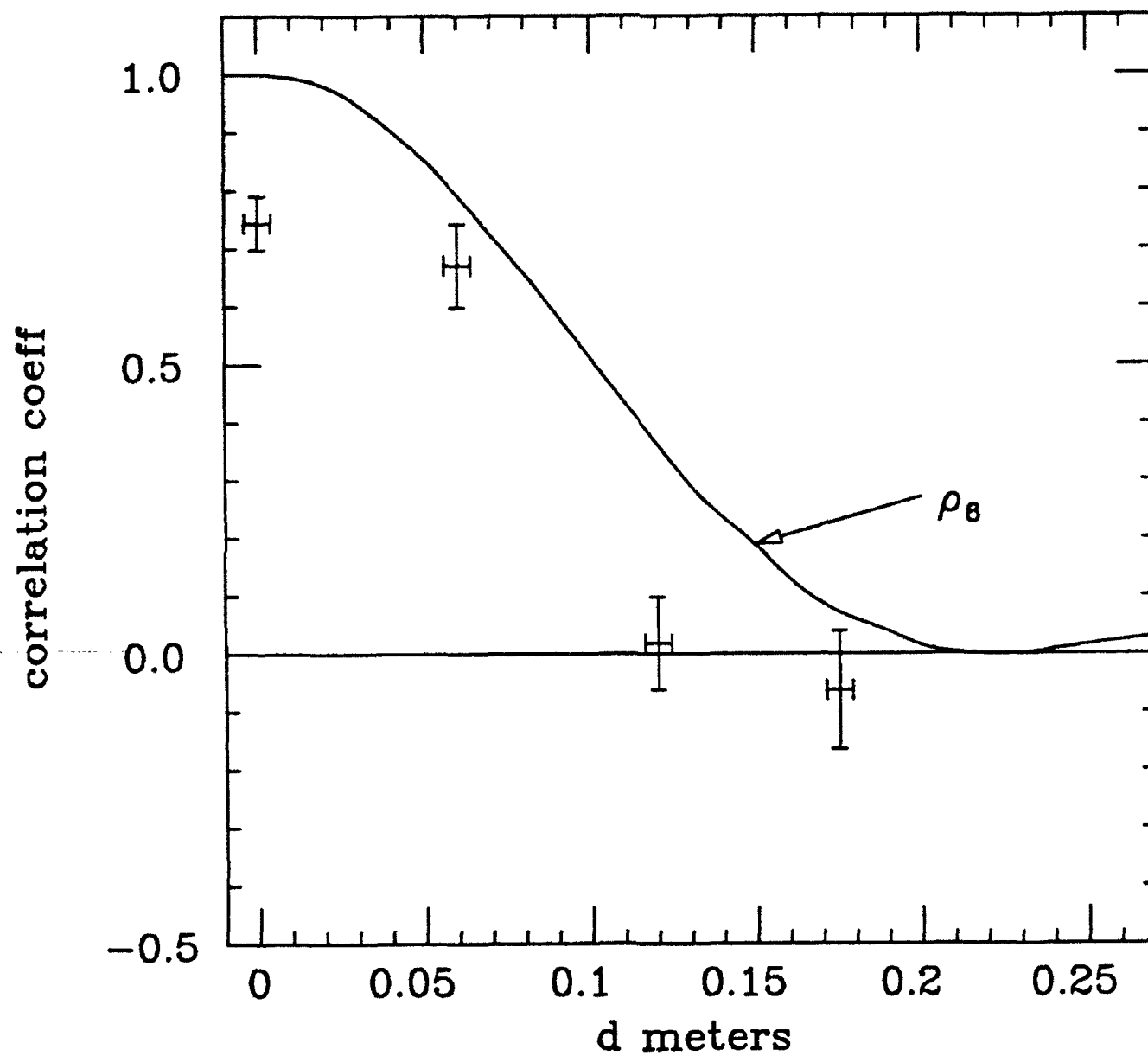Fig 2. n scattering planes (theoretical)

n=6; 6 scattering planes

Fig. 3